



# ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

## 2008-2010 Research Summary: Analysis of Demand Response Opportunities in California Industry

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## **ABSTRACT**

From 2008-2010, the Industrial Demand Response Team of the Demand Response Research Center (DRRC) continued its research into the potential for Demand Response (DR) and Automated Demand Response (Auto-DR) in the Industrial-Agricultural-Water (IAW) sector. Auto-DR refers to a technology and communications framework designed to:

- Provide customers with automated, electronic price and reliability signals;
- Provide customers with capability to automate customized DR strategies; and
- Automate DR, providing utilities with dispatchable operational capability similar to conventional generation resources.

Research continued into the implementation of DR and Auto-DR strategies in the three IAW sectors previously identified as having good potential for DR: refrigerated warehouses, data centers, and wastewater treatment. This included case studies and generation of sector specific research reports documenting details of facility characteristics and DR opportunities. The cement industry and agricultural irrigation were also identified as having DR potential, and were the subject of scoping studies.

As Auto-DR capabilities are strongly influenced by the sophistication of facility controls, research was also conducted to determine the state of controls in industrial facilities in California. This research resulted in a list of sector characteristics that appear to be conducive to DR along with the observation that case-by-case sub-sector analysis is often a necessary part of narrowing down focus areas.

Planned future research will deepen the knowledge of Auto-DR capabilities in the previously identified sectors, as well as broaden the scope of DR studies to include agricultural irrigation and other sectors identified by the control survey as having capacity for Auto-DR. Research will also be conducted into the potential for and implementation of shorter-notice, shorter-duration DR events.

Keywords: Demand response, industry, agriculture, water, energy efficiency

## EXECUTIVE SUMMARY

This report describes the work of the Industrial Demand Response (DR) Team of Lawrence Berkeley National Laboratory's Demand Response Research Center (DRRC) from 2008-2010, in the context of its mandate to conduct and disseminate research that broadens the knowledge base of DR strategies, with a focus on the Industrial-Agricultural-Water (IAW) sector. Through research and case studies of industrial sectors and entities, the DRRC-IAW Team continued to assimilate knowledge on the feasibility of industrial DR strategies with an emphasis on technical and economic evaluation and worked to encourage implementation of these strategies.

These strategies reduce total utility load during times of critical demand and market conditions which raise electricity supply costs, as well as improve reliability of the power grid allowing utilities to supply power more efficiently, in turn lowering the average energy cost to the consumer. To effect these changes, the DRRC focuses on policies and tariffs, the state of utility markets and technology, and customer technology and behavior.

This report builds on the key findings of the DRRC IAW Report for 2006-2008 (McKane *et al.* 2008), which identified several key success factors for DR, and especially Automated DR (Auto-DR), in IAW sectors. One of these success factors, the technical capacity to control specific systems and loads, was selected for further study during this 2009-2010 time period. In addition, three sectors were selected for additional research from a list of five identified in the 2008 report as having particular DR potential (See Appendix A of this report). These three sectors include: water/wastewater, refrigerated warehouses (cold storage), and data centers. Cement was added as a fourth sector of study in 2009, in response to findings from field work.

The planned objectives for this period were met:

1. Research reports were generated on energy efficiency and demand response in the wastewater treatment, refrigerated warehouses, data centers, and cement sectors (Thompson *et al.* 2008 & 2010a, Lekov *et al.* 2009, Ghatikar *et al.* 2010, Olsen *et al.* 2010).
2. Submetering studies and data analysis were conducted in the wastewater treatment and refrigerated warehouse sectors, providing additional insights to previous research from this field experience.
3. A controls survey was conducted to assess the state of controls technology across a broad spectrum of industries in California.

The research from this period sought to develop more granularity concerning key findings from the prior period (2006-2008), as summarized below:

1. *There appears to be great potential for Auto-DR in industrial facilities*, but the drivers for participation differ by company and by sector and are hindered by aversion to risk generally and, more specifically, the lack of perceived lack of control inherent in the term “Auto-DR”. The greatest potential for Auto-DR is believed to be in sectors with flexible production schedules and batch processes. Further research is needed to better understand:
  - organizational decision-making processes as they impact DR participation;
  - the role of existing and emerging industrial controls in facilitating participation in Auto-DR, and end-use process controls to support reduced service and process control levels during DR events; and
  - systems within an industrial facility that appear to have the greatest shed/shift potential such as: conveyors, pumping, cooling, compressed air, and other motor-driven systems.

Auto-DR is compatible with energy efficiency and load management in industrial facilities, and plants who express interest in Auto-DR are typically already engaged in both energy efficiency and demand management improvements. Auto-DR is often considered another cost-reduction tool, not a replacement for efficiency and demand management.

During the period addressed in this report, the Industrial DR Team started to conduct research on three sectors: refrigerated warehouses, data centers, and wastewater treatment facilities. The goals for the current period also included working with Technical Advisory Groups comprised of representatives from these sectors, and the suppliers and consultants that work with them. This research was to be directed toward key research questions to assist the California Energy Commission (CEC), the California Public Utilities Commission (CPUC), and the investor-owned utilities in more effectively targeting their Auto-DR efforts in the specific sectors of interest, and in particular to create conclusions extendable across entire sections or sub-sections of the industry.

Key activities included:

1. Wastewater Treatment:
  - a. Case studies of DR at two wastewater treatment facilities – These involved sub-metering the electricity consumption of the three major process areas that typically account for half of a wastewater treatment facility’s total usage, namely, influent/effluent storage pumps, solids separation

centrifuges and aeration area equipment. In one of the two plants, successful DR could be demonstrated, as well as theoretical possibility for Auto-DR, in pumps (36% of peak load) and solids separation centrifuges (30% of peak load). For the other plant, while there appeared to be significant potential, the facility staff indicated a reluctance to undertake any significant DR testing for operational and organizational reasons.

- b. Research report on Auto-DR potential at wastewater treatment facilities – Based on the first case study and extensive literature review.
2. Refrigerated Warehouses:
  - a. Detailed research report that documented Refrigerated Warehouses as a promising sector for Demand Response over a range of time scales, but with only a fraction of the available resources having been harnessed so far. These inherent abilities arise from refrigerated warehouses' significant power demand during utility peak periods, the fact that they are comprised of a limited number of well understood processes and due to the thermal mass of the building envelope and stored products allowing the stored products to ride out temporary reductions in cooling load.
  - b. Case studies of 2 successful utility incentivized Auto-DR implementations.
  - c. Analysis of manual DR data from 9 refrigerated warehouses.
3. Data Centers – Sector specific research report identified this sector as another major electricity consumer with a potential for energy savings and DR by way of prioritization of certain non-time-sensitive data processes (which account for bulk of the end-use energy usage), and by reducing the amount of “err on the side of caution” overcooling.
4. Cement Industry – Sector specific research report that documented a potential for significant energy savings and manual DR (but perhaps not Auto-DR due to the criticality of process equilibrium to the production process).
5. Controls Survey Report – This was based on a web based survey that was conducted, establishing a link between DR participation and controls capability in California industrial facilities. Specifically there are a set of characteristics that support DR participation, including advanced control systems, predictable loads, and a history of energy efficiency measures. Also, within broad industrial sectors there are many smaller sub-sectors whose operational nuances and thus potential for DR cannot be captured at the broad-sector level.

6. Agricultural Scoping Study – Preliminary investigation into the potential of what appears to be a promising sector for DR (this was undertaken over and above the original Amendment 1 deliverables).

High-level key findings from this period included:

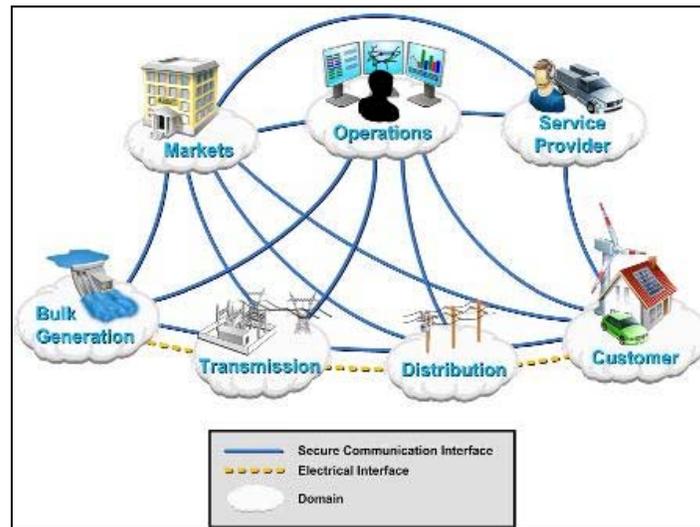
1. Preliminary research indicates that refrigerated warehouses and wastewater treatment are good candidates for DR due to their large, predictable loads and operational flexibility. Specific classes of equipment and systems with the most DR potential within the facilities were also identified.
2. Control technologies installed for energy efficiency and load management purposes can often be adapted for DR and Auto-DR at little additional cost.
3. DR potential, both technical and operational, of sectors within a major NAICS code can vary significantly, requiring analysis at a more detailed level to reasonably predict DR potential.

Planned activities for the next period include continuing research in the existing sectors of refrigerated warehouses, wastewater treatment, and data centers, as well as newly identified areas including agricultural irrigation, and additional sectors of promise emerging from the Industrial Controls Survey. The focus will be on developing event-based as well as continuous (shorter time frame, quick acting) demand response capabilities in California industry, and aggregation of these capacities to harness system-wide synergies to maximize benefits. These will be achieved by identifying implementation strategies, guiding policy development, and quantifying the economic benefits as a sustainable roadmap for adoption. Additional work will continue to be structured in consultation with CEC, based on California's requirements and ongoing results of this research.

# 1.0 Introduction

Demand Response (DR) is a set of actions taken to reduce electric loads when contingencies such as emergencies or congestion occur that threaten supply-demand balance and/or market conditions occur that raise electric supply costs. A real-time Automated Demand Response (Auto-DR) infrastructure to optimally manage and link electric supply and demand side systems is becoming increasingly important in the context of the California Energy Commission (CEC) goals of achieving 534 megawatts (MW) of peak demand reduction and 1 gigawatt (GW) of ancillary services storage by 2020. This infrastructure must be compatible with requirements of electric system grid operators and electric utility companies, including those arising from the assimilation of a greater amount of renewable and clean energy generation capacity, while continuing to serve the loads and needs of electricity customers. Figure 1 shows the conceptual model of the Smart Grid, a planned modernization of the US electrical grid under development by the National Institute of Standards and Technology (2010) that would enable real-time electricity transactions such as Auto-DR.

**Figure 1: Interactions of actors in different Smart Grid domains through secure communication and electricity flows.**



The Industrial-Agricultural-Water (IAW) sector accounted for 30% out of the state’s approximately 60 GW of peak electric load in 2010 and has the potential to be a key contributor to DR and Energy Efficiency (EE) goals in California. Related benefits could include:

- Jobs, economy – Positioning California-based companies to provide DR implementation services and technical support to the industrial, agricultural, and

water sectors in the rest of country. California is already a national leader in IAW DR and EE programs. DR implementation requires specialized skills that leverage a history of technology innovation, renewable energy resources, investment capital and supportive government policies. Industry – Reliability benefits arise from the fact that DR lowers the likelihood and consequences of forced outages that impose operational and financial burden on industrial consumers.

- Market – Lower wholesale market prices result because DR averts the need to use the most costly-to-run power plants during periods of otherwise high demand, driving down overall per unit production costs.
- Ratepayers – Sustained DR lowers aggregate system capacity requirements, allowing utilities to build less new capacity, thus avoiding costs that would otherwise be passed onto retail customers.
- 2020 needs of the grid – DR helps in addressing challenges arising from the assimilation of a greater amount of intermittent renewable and low-carbon generation capacity, while continuing to reliably serve the loads and needs of electricity customers.

## **1.1. Role of the Demand Response Research Center**

Since its formation in 2006, the goal of the Demand Response Research Center’s (DRRC) industrial team has been to facilitate deployment of industrial DR that is economically attractive and technologically feasible. In order to address these imperatives, the DRRC has strived to spearhead multi-disciplinary research initiatives involving:

- Customer technology and behavior,
- Policies and tariffs, and
- State of utility markets and technology.

The objectives of these efforts have been to:

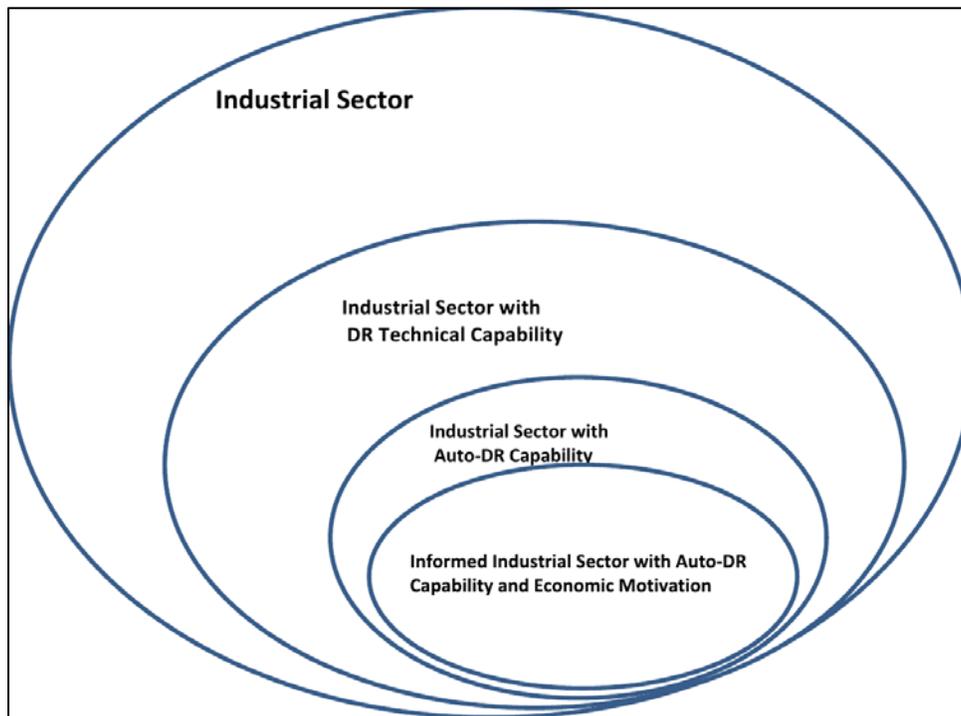
- Reduce total utility load during times of critical demand and market conditions,
- Improve reliability of the power grid allowing utilities to supply power more efficiently, and
- In turn lower the average electricity cost to the consumer, by way of both the above.

The Industrial Sector is diverse, and an early challenge had been to identify sectors of promise. Initially, based on conventional knowledge, refrigerated warehouses, data centers, wastewater/water, aerospace products, and beverage sectors were short-listed as low-hanging fruit. But industrial facilities are not primarily concerned with DR, focus

being on their own production – so unless the technology platform is showcased, operational flexibilities demonstrated and financial incentives evident, many facilities are not willing to consider the potential benefits of DR.

Figure 2 below depicts a conceptual framework of the DRRC IAW DR research as it relates to the industrial sector. Only the energy users in the smallest diagrammed subset will reliably contribute to Auto-DR events. This framework guides the IAW research, with the goal of assisting the CEC, the California Public Utilities Commission (CPUC), and the investor-owned utilities in more effectively targeting their Auto-DR efforts.

**Figure 2: Discovery Process for Industrial Auto-DR Implementation**



Auto-DR can be accomplished by a multitude of technical solutions. In order to reduce the extent of stranded assets, the DRRC has led the development of an open standard for Auto-DR implementations, known as Open Automated Demand Response (OpenADR). The OpenADR standard is developed by a public-private partnership known as the OpenADR Alliance. Version 1.0 of the standard was released in 2009 (Piette *et al.* 2009).

## 1.2. Research in Industrial Sectors

During this period, the DRRC-IAW Team continued research in three sectors showing good DR potential – wastewater, refrigerated warehouses, and data centers. In addition, the Team worked closely with DRRC Buildings colleagues since past experience with some of the demand response strategies proven successful in commercial buildings may also be applicable to industrial facilities such as refrigerated warehouses and data centers.

Apart from these existing sectors, the DRRC is also poised to further research in other newly identified sectors of promise also, with a view to developing event-based as well as continuous (shorter time frame, quick acting) DR capabilities in California industry, and aggregation of these capacities to harness system-wide synergies and generate benefits that are greater than the sum of the parts. These are foreseen to be achieved by focusing on identifying implementation strategies, guiding policy development, and quantifying the economic benefits as a sustainable roadmap for adoption.

## 2.0 Current Research

### 2.1. Wastewater Treatment

Extensive literature search, data collection and analysis were conducted in this sector. This generated:

1. Research report entitled “Automated Demand Response Opportunities in Wastewater Treatment Facilities” (Thompson *et al.* 2008),
2. Data Analysis Report on submetering conducted at San Luis Rey Wastewater Treatment facility in Oceanside, California (Thompson *et al.* 2010a), and
3. Submetering data collection at South East Wastewater Treatment facility in San Francisco, California.

The key aspects of this research have been summarized below.

Wastewater treatment is an energy intensive process, which along with water treatment comprises about 3 percent of US annual energy use. In California, water and wastewater treatment account for 5 percent of energy use, and there are more than 852 municipal wastewater treatment facilities with average demand reaching 300 megawatts (MW) each, yet wastewater treatment facilities are an often overlooked area for automated demand response opportunities. In order to assess this potential in wastewater treatment facilities, the magnitude of energy use and patterns of demand in

these facilities was analyzed, and submetering studies were done to understand the role of energy intensive equipment (Thompson *et al.*, 2008).

Load variation in wastewater treatment facilities depends on many factors including seasonal and daily load patterns, location, population size, and whether facilities are municipal or industrial. For example, many manufacturing facilities have fairly constant wastewater flow rates during daily production, but these can change dramatically during cleanup and shutdown. Industrial wastewater flow rates vary in this manner depending on the time of day, day of the week, season of the year, or sometimes the nature of the discharge. For municipal treatment facilities, wastewater flows often follow a diurnal pattern where the peak flows occur twice a day: once in the late morning when wastewater from the peak morning water use reaches the treatment facility and a second peak flow during the early evening between 7 and 9 p.m.

**Figure 3: Power consumption of a wastewater treatment facility over one week**

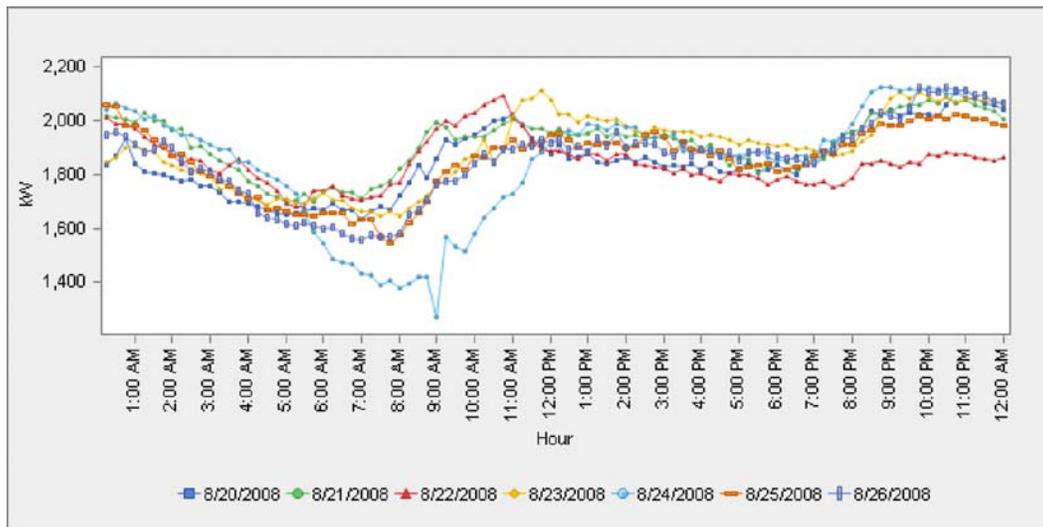


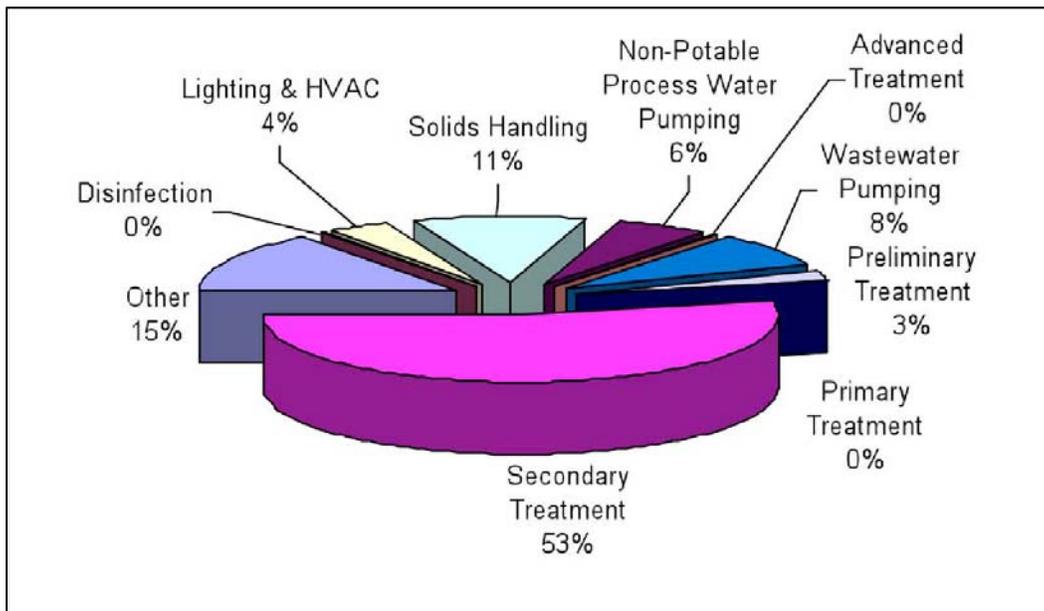
Figure 3 shows a sample summer load pattern for a municipal wastewater treatment facility. Wastewater treatment facility electricity demand is high during the summer months, particularly in areas with hot summers like Southern California. The facility demand required for treating and transporting wastewater is significant during the peak electricity demand periods experienced by the electrical utilities. This, combined with the characteristic energy-intensity of the wastewater treatment process, makes wastewater treatment facilities prime candidates for automated demand response.

In 2001, wastewater treatment facilities in California consumed 2 billion kilowatt-hours (kWh) of electricity. Within these facilities, the energy intensity for water collection and treatment ranged from 1,100 kWh/million gallons to 4,600 kWh/million gallons, with an average of 1,200 kWh/million gallons (Thompson *et al.* 2008). One of the reasons for this

wide range is the variability in transporting and pumping wastewater. The average amount of electricity used for transporting and pumping wastewater from a residential or commercial area to a municipal wastewater treatment facility is 150 kWh/million gallons, but this value can vary greatly depending on wastewater treatment facility topography, as well as system size and age. Some wastewater collection systems rely on gravity to transport wastewater to a treatment facility, while others use energy intensive pumps to lift or transfer the wastewater. Further reasons for the variability in wastewater treatment energy intensity include the dependence of energy use on the quality of the waste stream, the level of treatment required to meet regulations, and the treatment technologies used. A New York State Energy Research and Development Authority study found that the national average energy intensity for wastewater treatment was 1,200 kWh/million gallons. New York State's average energy use for treating wastewater was 1,067 kWh/million gallons for large facilities (those processing more than 75 million gallons per day) and 3,749 kWh/million gallons for small facilities (those processing less than one million gallons per day), with a statewide average of 1,353 kWh/million gallons, a range similar to that seen in California. The energy use in large facilities is much lower than in small facilities, and the large facilities process a significantly higher portion of wastewater, bringing the average to the lower end of the range.

The potential for implementation of automated demand response and energy saving measures depends on the technologies involved in the wastewater treatment process. Wastewater is generally treated by removing coarse and suspended solids and organic matter from the waste stream through screens and sedimentation in the primary treatment process. It is then aerated in secondary treatment, which raises the dissolved oxygen levels, helping promote the growth of microorganisms which remove the remaining soluble and organic material. Finally, nutrients and toxic compounds are removed and the water is chemically disinfected. Figure 4 shows the average distribution of energy end-uses in the municipal wastewater treatment process based on eight municipalities in New York State.

**Figure 4: Energy end-uses for a sample of wastewater treatment plants in New York State**



The energy use by individual equipment in the wastewater treatment process plays an important role in formulating automated demand response strategies since energy-intensive equipment should be the primary target for demand response. The most energy-intensive equipment in a wastewater treatment facility are pumps and aerator fans. The energy required for influent wastewater pumping can range from 15 to 70 percent of the total electrical energy depending on the wastewater treatment facility site elevation and influent sewer elevation. In many cases, wastewater treatment facilities with diffused aeration systems can use 50 to 90 percent of their facility's electric power demand to run aerator blower motors. Developing demand response strategies focusing on this key equipment is expected to result in the most significant load reductions.

#### 2.1.1. Wastewater Treatment Facility Controls

Control systems are essential for automating demand response strategies in wastewater treatment facilities. The use of centralized computer controls, such as Supervisory Control and Data Acquisition (SCADA) systems in wastewater treatment facilities is increasing by about five percent annually. The introduction of centralized controls integrates existing standalone controls or distributed control systems, improving operational efficiency and facilitating the automation of demand response strategies.

Centralized control systems allow for integrated data collection and analysis, and provide opportunities to improve overall facility performance. Within wastewater treatment facilities, SCADA systems direct when to operate remote equipment and

make complex decisions based on input from the system. These systems provide continuous and precise control of process variables and can start, slow down, or stop equipment when monitored process information such as flow rates and dissolved oxygen levels deviate from pre-established parameters. SCADA systems can be programmed to monitor and automatically adjust equipment in response to deviations from preset levels for biological oxygen demand, air density, blower efficiency, and facility flow on a real time basis, and meet discharge regulations with better control at the treatment level.

Centralized control systems allow for more efficient overall operation of all facility systems, and provide an entry point to the facility to implement automated demand response strategies.

### 2.1.2. Automated Demand Response Strategies

The technologies that enhance efficiency and controls within wastewater treatment facilities could also enable these facilities to become successful demand response participants. Comprehensive and real-time demand control from centralized computer control systems can allow facility managers to coordinate and schedule load shedding and shifting through equipment-level controls to reduce energy demand during utility peak hours. This section outlines several load shedding and load shifting opportunities that could be successful in wastewater treatment facilities.

Opportunities for load shedding during demand response events include turning non-essential equipment off and transitioning essential equipment to onsite power generators. Generation equipment using diesel or natural gas may be subject to restrictions on annual operating hours (e.g. California Code of Regulations §93115), but if biogas can be stored then it can be used to effectively shift loads outside of peak periods or demand response events. Equipment loads which can be potentially shed during peak hours include aerator blowers, pumps, and facility heating ventilation and air conditioning (HVAC) systems. Alternatively, facilities can use variable frequency drives to operate this equipment at lower capacity which reduces demand and better matches the requirements for operation within regulatory limits. Centralized control systems can provide wastewater treatment facilities with an automatic transfer switch to running onsite power generators during peak demand periods. Onsite power generators running on anaerobic digester gas, a byproduct of the treatment process, can also provide off-grid power during demand response events. This strategy has been proven successful in municipal wastewater treatment facilities. The East Bay Municipal Utilities District has implemented a load management strategy which includes a digester cover that stores anaerobic digester gas until it can be used during peak-demand periods. Implementing load shifting strategies in wastewater treatment

facilities allows the main energy-intensive treatment processes to be rescheduled to off-peak hours.

A major opportunity for shifting wastewater treatment loads from peak demand hours to off-peak hours is over-oxygenating stored wastewater prior to a demand response event. This allows aerators to be turned off during the peak period. However, facilities must be careful to monitor and maintain the correct range of aeration since over-oxygenation due to prolonged detention time can also adversely affect effluent quality. Further, if site conditions allow, wastewater treatment facilities can utilize excess storage capacity to store untreated wastewater during demand response events and process it during off-peak hours. Facility processes such as backwash pumps, biosolids thickening, dewatering and anaerobic digestion can be rescheduled for operation during off-peak periods, providing peak demand reductions in wastewater treatment facilities.

To better understand opportunities for demand response control strategies in wastewater treatment facilities and evaluate how such strategies perform in actual facilities, submetering data from two California wastewater treatment facilities was analyzed (Thompson *et al.*, 2008).

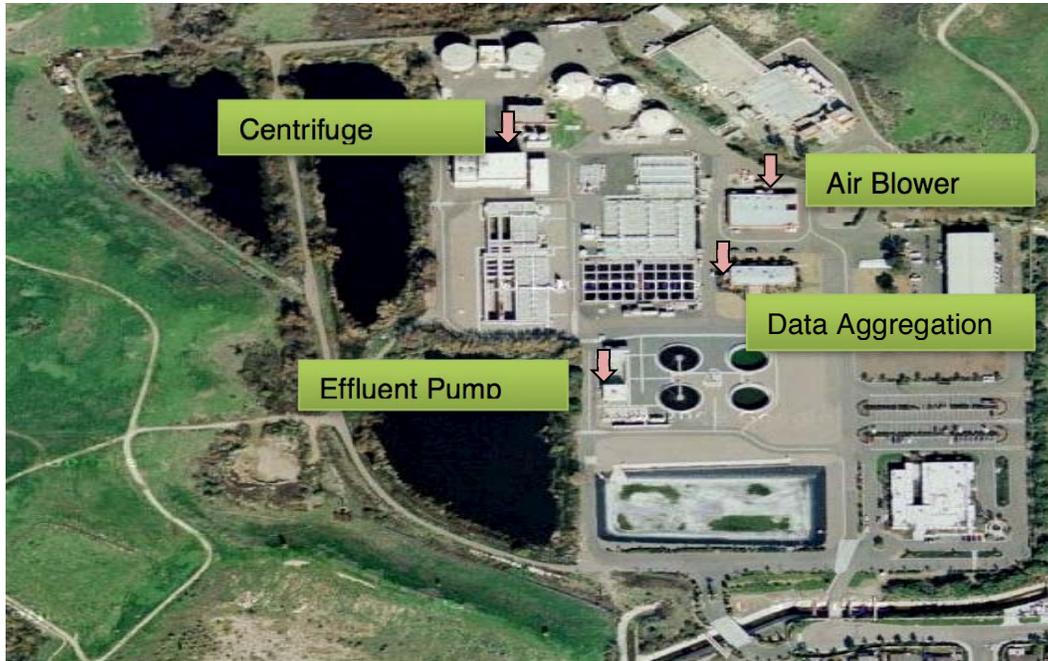
### 2.1.3. San Luis Rey-Oceanside Submetering Demonstration Project

In October 2009 Lawrence Berkeley National Laboratory (LBNL) began submetering the San Luis Rey Wastewater Treatment Plant, located in Oceanside, California, to determine the load profile of the key energy end uses and assess the demand response potential of California municipal wastewater treatment facilities. San Luis Rey is a medium size wastewater treatment facility which processes about 11 million gallons of wastewater daily and is representative of many similar facilities in California. A report was developed upon completion of the 100 day submetering period from 10/2/2009 – 1/10/2010 at the plant (Thompson *et al.*, 2010a). Turnkey project management and on-site installation of the data logger and all other end-use devices was provided by the subcontractor Southern Contracting. A summary of the findings were presented at the DistribuTech conference in San Diego in February 2011 (Thompson *et al.* 2010b).

The energy usage and demand of key equipment at the treatment plant were submetered, including effluent pumps, blowers, and centrifuges. Equipment locations are shown in Figure 5. Additional data were collected from the facility and various external data sources, including influent and secondary effluent flow, pH, dissolved oxygen levels, temperature, humidity, and effluent turbidity. The report presented the findings of this data collection and analysis and the results of manual demand response tests conducted on the major energy using equipment. Although the equipment and resources did not exist to conduct Auto-DR, it was expected that these results would

provide a basis for analyzing Auto-DR potential as well. These findings were augmented with insight from the San Luis Rey's operations manager.

**Figure 5: Locations of power meters at San Luis Rey Wastewater Treatment Plant**



The analysis found that the effluent pump load at the facility remained constant at 300 kW during normal facility operations. The centrifuge load also was steady at 40 kW during operation, but this equipment was shut down over the weekends. The aeration blower load typically varied between 200 and 300 kW. This study found no correlation between the influent flow to the facility and the average dissolved oxygen levels measured in the wastewater. A slight correlation was seen between the outdoor air temperature and dissolved oxygen levels. A small correlation was seen between influent flow and outdoor temperature.

Several areas of the plant were found to have potentials for demand response including the submetered areas of effluent pumps and centrifuges. Demand response tests on the effluent pumps at the San Luis Rey facility revealed the potential for a 204 kW (36 percent of pump load) peak period load reduction, and a maximum load reduction of 300 kW during the test. Tests on centrifuges revealed a peak period load reduction of 10 kW (30 percent of centrifuge load), and a maximum load reduction of 40 kW during the test. During demand response tests on facility blowers, peak period load reductions of 78 kW (31 percent of blower load) were seen. The blowers, however, might have to be excluded from DR events. The facility manager noted that 24 hours after this test occurred there was a sharp peak in secondary effluent turbidity lasting about 5 hours,

indicating that the total solids in the system were high. He stated that if the turbidity were to go above the turbidity limit of 10 NTU and remain above that level for more than eight hours, the plant would violate its permit from the Environmental Protection Agency (EPA). This conclusion is likely applicable to other similar municipal wastewater treatment facilities.

The results of most of the manual demand response tests revealed that the San Luis Rey Wastewater Treatment Plant was able to reduce a significant amount of its electricity demand for short periods (2-5 hours) during normal facility operations, indicating that it has excellent potential as a candidate for Auto-DR. Auto-DR improves participation in DR programs due to the fact that utility-initiated DR actions are automatically executed at facility level on the basis of a pre-programmed end-use control hierarchy with opt-out provision, rather than via human attention/intervention to execute a process that often gets subordinated to operational exigencies.

Although the demand response tests at the facility were successful, at the time of the tests, the cogeneration capabilities at the San Luis Rey facility were restricting the plant's effective demand response potential. This is because the utility required that the facility always have a positive net load draw. Thus, the total demand from the facility's equipment always had to be greater than the power generated by the cogeneration system, limiting the depth of load reductions. Because the facility's cogeneration capacity is such a large proportion of the total load, the San Luis Rey facility had few options in terms of demand response measures, especially as the site continued to become more energy efficient. However, under a subsequent decision by the California Public Utilities Commission (CPUC Decision 12-05-035, effective May 24, 2012), large utilities may be required to purchase excess cogeneration power generated under a feed-in tariff. The previous eligibility limit was 1.5 MW; this was raised to 3 MW by the new decision.

This study confirmed that municipal wastewater treatment facilities are good candidates for automated demand response. These facilities are highly energy-intensive and key equipment such as pumps and centrifuges can be targeted for large load reductions. However, this research has also revealed that demand response strategies for aeration blowers may result in a short-lived decline in secondary effluent quality in municipal facilities.

#### 2.1.4. San Francisco-Southeast Submetering Project

Similar in scope to the San Luis Rey study, but for a slightly different wastewater treatment process, submetering began in August 2010 at the Southeast Water Pollution Control Plant, in San Francisco. The plant's four main lift pumps and six centrifuges were submetered, and data on the total power demand of the plant, power demand of

external pump stations, and key plant operating parameters were sent by plant staff. When significant changes were made to operating equipment, the plant notified LBNL of the changes made. The equipment was left in place for a year, and the data collected is being analyzed for evidence of demand response opportunities. Preliminary conclusions include:

- Lift pump and centrifuge power demand were highly variable, and each showed the potential for sheds of 100 kW or more for several hours, dependent on material flow constraints.
- The combined demand of external pump stations typically was greater than 1 MW. Some load from these pumps could be shed, dependent on wastewater collection bottlenecks.
- The energy used to treat a volume of wastewater was 40% higher in the dry half of the year compared to the wet half. Significant on-peak energy could be saved during dry months by turning down equipment operating levels or disabling aeration trains.

The main differences between this plant and San Luis Rey include that fact that this plant's treatment process uses an oxygen plant instead of aeration blowers to cater to biological oxygen demand, and a co-generation reimbursement agreement that involves a mandatory sale of all the on-site electricity generation back to the grid. In other words, while the San Luis Rey facility is obligated to use all of its cogenerated electricity, the San Francisco facility is obligated to sell it all back to the grid and repurchase during peak demand times. While the former limited the scope for load curtailment, the latter reduced the financial benefits of peak period load curtailment, both of which hinder EE and DR. Electricity tariffs and incentive structures can be dissimilar across similar facilities and often change over time.

#### 2.1.5. Conclusions and Future Directions

Wastewater treatment is an energy intensive process with high electrical load during the utility peak demand periods, and energy-intensive equipment offer significant potential for automated demand response. Integrated centralized control systems are becoming more commonplace in wastewater treatment facilities, improving operational efficiency and allowing for greater control of facility processes. These controls can also be used in the integration of automated demand response strategies. Loads can be shed or shifted through lowering the throughput of aerator blowers, pumps and other equipment, temporarily transitioning to onsite power generators, anticipatory over-oxygenating of wastewater, or storing wastewater for processing during off-peak periods. In particular, large load reductions can be seen by targeting effluent pumps and centrifuges. Limiting factors to implementing demand response are the reaction of

effluent turbidity to reduced aeration load, along with the cogeneration capabilities of municipal facilities, including existing power purchase agreements and utility receptiveness to purchasing electricity from cogeneration facilities.

While only a few of the demand response opportunities outlined above have been tested and proven as successful load management strategies, similar activities have long been incorporated as energy efficiency measures in wastewater treatment facilities. The success of energy efficiency opportunities in these facilities, combined with the increased use of centralized control systems, demonstrates the potential for automated demand response. Furthermore, the magnitude of the load in these facilities alone suggests the extent of demand response reduction potential, and indicates the need for further study of automated demand response in wastewater treatment facilities.

This research has identified opportunities for additional study that would build on the body of knowledge developed through LBNL's wastewater treatment research. Some these areas could include:

1. Enhancing understanding of the effect of aeration blower shutdown on secondary effluent quality.
2. Utilizing the results of the Industrial Controls Survey and discussions with control experts to better understand existing controls capability in wastewater treatment facilities.
3. Conducting further studies to understand the prevalence of cogeneration in wastewater treatment facilities and its relationship to DR potential.
4. Continuing to survey the literature for case studies and technology advances that might affect OpenADR potential.
5. Scaling and standardizing the OpenADR for control systems to apply to wastewater treatment facilities to reduce implementation cost, and increase DR reliability and effectiveness.
6. Improving understanding of how facility operations impact the effectiveness of DR strategies and identify the best operation practices and behaviors to enhance the impact of DR activities.

Planned research for the next period includes interviewing personnel from a selection of wastewater sites (approximately 20) in order to gain more comprehensive knowledge of the wastewater industry and develop a preliminary DR potentials profile from non-DR participants, preparing an issues paper based on completed and current research to lay the basis for a future DR Strategy Guide scoping draft, and assessing the potential to use the intermediate wastewater treatment stages as a non-thermal process/material storage medium for load shifting/shedding and grid response.

## 2.2. Refrigerated Warehouses

Industrial refrigerated warehouses are well-suited to shift or shed electrical loads in response to utility financial incentives and were selected in 2008 as one of the foci of Lawrence Berkeley National Laboratory's (LBNL) Energy Efficiency (EE) and Demand Response (DR) research because:

- Refrigerated warehouses are energy-intensive facilities that have significant power demand during the utility peak periods,
- Most refrigerated warehouse processes are not sensitive to short-term (2–4 hour) lower power operation, and in many cases demand response activities are not disruptive to facility operations,
- The number of processes conducted in these facilities is limited and the processes are well understood,
- Past experience with some of the demand response strategies proven successful in commercial buildings may be applicable to these facilities, and
- Some refrigerated warehouses already have the control systems required for load management programs, as well as experience in energy efficiency.

As part of a continuing effort to create an improved understanding of the potentials, challenges and current state of this sector, extensive literature search, data collection, and analysis were conducted. This generated:

1. Research report phase I, entitled "Opportunities for Energy Efficiency and Automated Demand Response in Industrial Refrigerated Warehouses in California" (Lekov *et al.* 2009).
2. Case studies of EE and DR results at two Refrigerated Warehouses in Pacific Gas and Electric's (PG&E) service territory, Amy's Kitchen and US Food Service (Faulkner and McKane 2010a & 2010b).
3. Analysis of load sheds and shifts from baseline electricity use at nine refrigerated warehouse customers of PG&E during the 2009 Critical Peak Pricing (CPP) season.

Salient aspects of the above research are summarized below.

In May 2009, a research report was generated studying the potential opportunities and barriers related to implementing OpenADR in the refrigerated warehouses sector, both practical and perceived (Lekov *et al.*, 2009). Some of these include the wide variation in loads and processes, resource-dependent loading patterns that are driven by outside factors such as customer orders or time-critical processing, the perceived uncertainties

associated with the control capabilities for implementing OpenADR strategies, and concerns about interrupting the scheduled processes and assuring product quality.

The Lekov report was compiled after extensive research concerning refrigerated warehouse specifications, demand response strategies, and energy efficiency upgrades. The literature search included 54 sources ranging from peer-reviewed studies describing the demand response-related technologies and equipment controls to case studies of energy efficiency and demand response applications. While the literature provides relatively comprehensive information about the basic equipment and controls included in the design of the refrigerated warehouse facilities, it has little information about the demand response potential of the existing controls and equipment. The study utilized LBNL staff experience from participating and planning demand response programs for several facilities, including demand control related discussions with facility technical staff. In addition, the study used information from recent utility reports to describe the potential demand response strategies in refrigerated warehouses. Data from field studies of three refrigerated warehouses sites that participated in a series of demand response events were analyzed in order to understand which strategies were most successful in achieving load reduction.

Key findings from the report included that facilities which have implemented energy efficiency measures and have centralized control systems can be excellent candidates for Auto-DR under the OpenADR protocol, due to equipment synergies, as well as increased confidence among facility management of the potential for controlling energy costs without disrupting facility operations. The main reasons for the sites' participation in automated demand response programs were to take advantage of utility incentives, improve facility power system reliability, and save on utility bills.

Further:

1. Applying demand response strategies in industrial refrigerated warehouses could reduce California's peak demand. The electrical load from California's refrigerated warehouses in 2008 was about 360 MW with an estimated potential demand reduction ranging from 45–90 MW. Assuming a relatively modest 20 percent participation rate, the demand reduction could range from 9–18 MW in California without much noticeable impact on operations.
2. While cold storage provides a significant potential for load reduction, other facility end use may also offer opportunities for load reduction. One facility analyzed was able to reduce its load by 28 percent primarily with cold storage reductions. Another site was able to reduce its load by 21 percent primarily by reducing other end-use demand. Cold storage was shown to comprise a large

percent of the electricity load in refrigerated warehouses, making it the primary target for load shedding or shifting.

The following charts depict the above conclusions. Figure 6 shows data from one of the studied sites that achieved a majority of its demand reduction from cold storage. When compared to the 3/10 baseline (CPP Baseline) during event day peak periods, the total facility demand decreased from an average of 291 kW to 210 kW, or 28%. It achieved these load reductions by turning off compressors and letting the refrigerated warehouse temperature drift. The average temperature drift during the demand response events was 8 °F.

**Figure 6: Energy performance of a refrigerated warehouse during a demand response event compared to baseline energy usage**

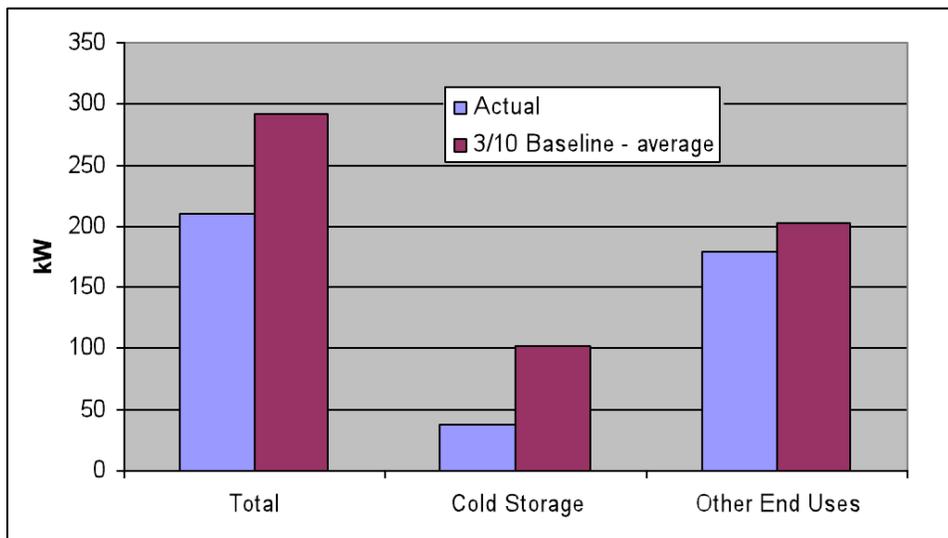
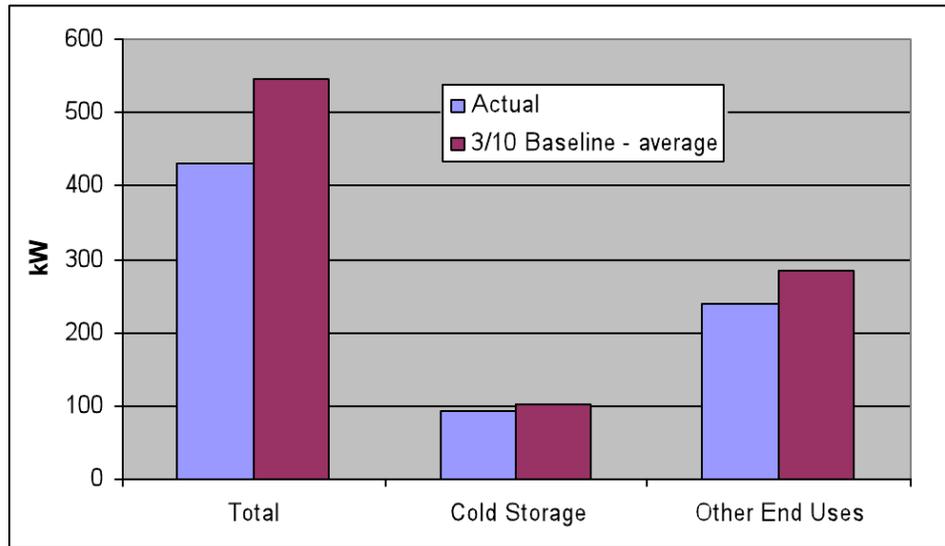


Figure 7 shows data from another site that achieved the majority of its demand reduction from loads other than cold storage. When compared to the 3/10 baseline during event day peak periods, total facility demand decreased from an average of 544 kW to 430 kW, or 21%. This site achieved these other end use load reductions through curtailing site processes and shutting off various building loads.

**Figure 7: Energy performance of a refrigerated warehouse which achieved its demand reduction from loads other than cold storage**



This research identified opportunities for additional study that build on the body of knowledge in this report, including:

1. Utilizing the results of the Industrial Controls Survey and discussions with control experts to better understand existing controls capability in refrigerated warehouses.
2. Continuing to perform field studies, or team up with partners who are in a position to share such data, to add to the body of knowledge about OpenADR implementation experience in the refrigerated warehouses sector; collect data to quantify the impact and relationship between parameters that affect the success of automated demand response strategies, including the impact of product mass, storage facility envelope, cooling capability, and varying ambient conditions.
3. Continuing to survey the literature for case studies and technology advances that might affect OpenADR potential.
4. Coordinating with California utilities to develop a better understanding of the life cycle of the existing stock of refrigerated warehouses, both for equipment and structural.
5. Developing the Refrigerated Warehouses Demand Response Strategy Guide, using the findings from the Lekov report and the above activities as a starting point.
6. Assessing the feasibility of developing a DR Quick Assessment Tool for Refrigerated Warehouses building on office and retail tools. This would benefit refrigerated warehouses operators by providing them with the capability to

assess facility performance within some range of performance criteria thus enhancing their capabilities to implement OpenADR.

7. Scaling and standardizing the OpenADR for control systems to apply to refrigerated warehouses to reduce implementation cost, and increase DR reliability and effectiveness.
8. Improving understanding of how facility operations impact the effectiveness of DR strategies and identify the best operation practices and behaviors to enhance the impact of DR activities.
9. Improving marketing and recruitment of industrial refrigerated warehouse sites for DR incentive programs to improve the low participation rates. Emphasize the financial benefits of participation in DR, the improved consistency of participation resulting from Auto-DR, and the absence of adverse effect on operations arising from participation via Auto-DR.

### 2.2.1. Refrigerated Warehouse Case Studies

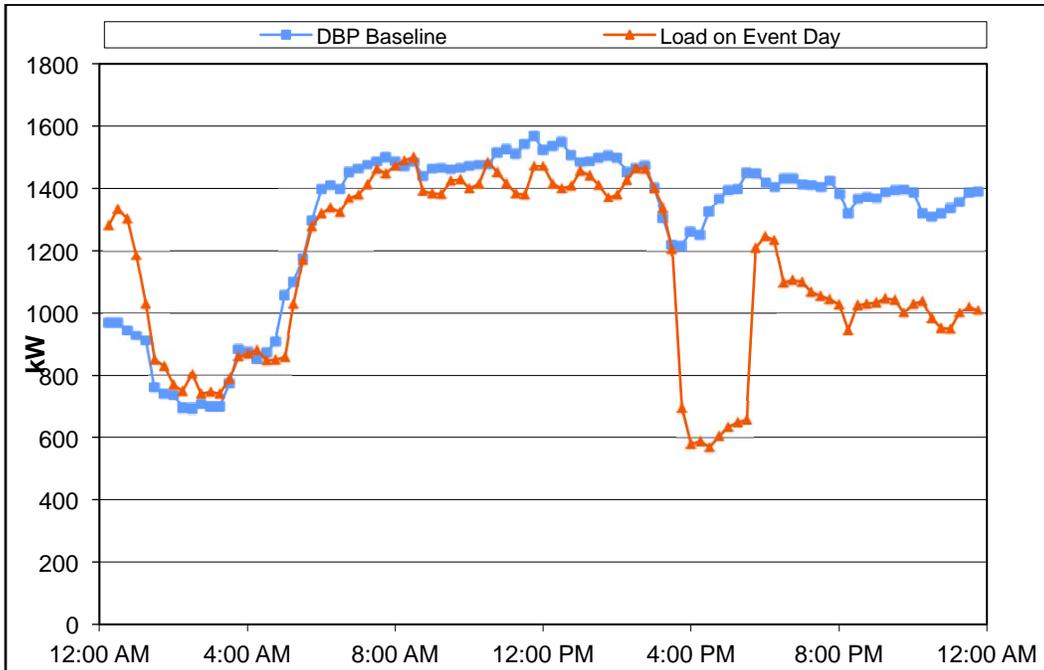
Case studies were conducted at two refrigerated warehouses in PG&E's service territory: Amy's Kitchen and US Foodservice, both of which significantly lowered peak demand with OpenADR controls (Faulkner and McKane 2010a & 2010b).

Amy's Kitchen's Santa Rosa plant is a food processing and cold storage facility that includes several large cool rooms, a variety of static and continuous freezers, plus HVAC and lighting loads. In 2008, the facility's electrical end-use applications had an average aggregate baseline demand of 1,600 kW with a peak demand of 1,900 kW, of which nearly 12% was from a single spiral freezer.

The load shed estimation assessment performed by controls vendor Powerit found that this facility was well-suited for Auto-DR because many freezers and cool rooms have fairly predictable loads that could withstand temporary temperature increases. At the time of assessment, the facility was not equipped with any industrial process control systems or the communications infrastructure needed to implement Auto-DR. Powerit designed and installed a predictive energy management system that could control the industrial processes and enabled OpenADR across the entire facility. Amy's Kitchen retained the ability to opt-out of events or override the demand response strategy in the event that production or temperatures were adversely affected beyond control limits.

The project was successful, with electricity demand reduction of 580 kW, or approximately 36% load shed over a 2 to 4-hour event period, compared to the DBP baseline (as seen in Figure 8). Production was unaffected and in fact saw improved process control. Amy's Kitchen received \$139,200 in incentive payments from the utility and potential additional incentives for future events, translating to a simple payback period of less than a year.

**Figure 8: Energy performance of Amy's Kitchen on a DR event day compared to DBP baseline**



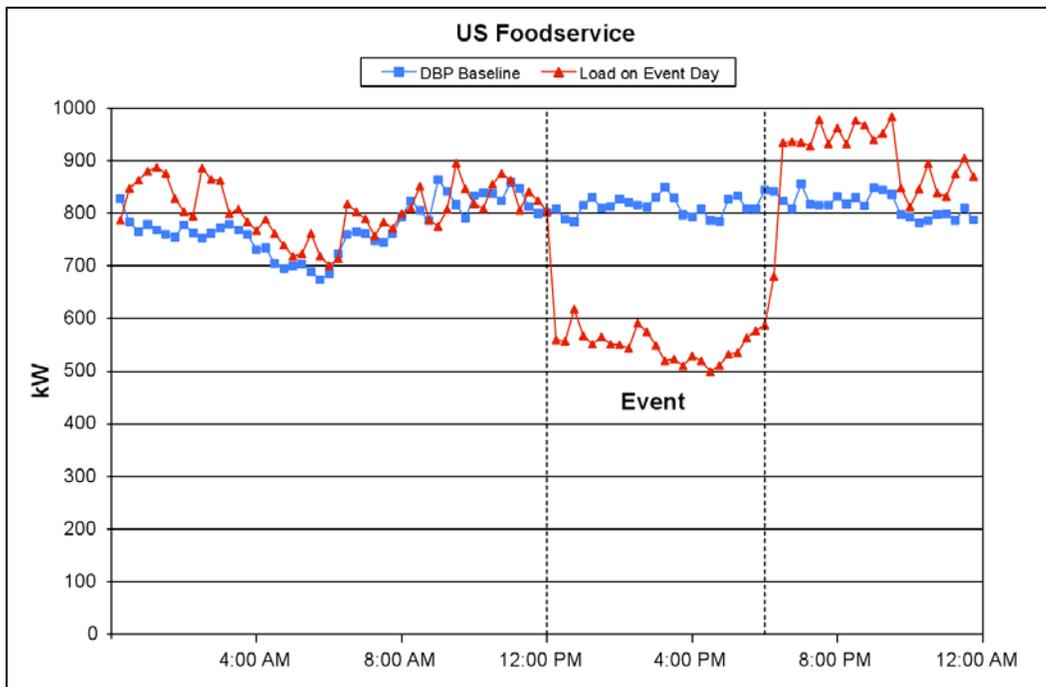
U.S. Foodservice in Livermore is a cold storage food distribution center storing over 10,000 different types of food products. It includes a large 345,000 sq. ft. freezer maintained between -1 and +1 °F. Electricity demand for the entire site ranges between 700 and 900 kW, of which 30-40% is used by the freezer. It was considered an optimal site for OpenADR because the facility's freezer and HVAC systems have stable loads. It also already had some of the controls and communications infrastructure and a building energy management control system (EMCS) that could easily be utilized for OpenADR.

Compared to the Demand Bidding Program (DBP) baseline, U.S. Foodservice was able to shed an average of 25% of its load (more than 200 kW) during testing without adverse effects, with a maximum shed of 41% (330 kW). Test data from the facility can be seen in Figure 9. Shutting off the air handlers in the freezer had the largest impact, but adjusting the setpoint on the HVAC system also helped shed 25 kW. By the end of each 6-hour testing period, the air temperatures near the doors in the freezer had risen by 8.6 °F, while near the far walls of the freezer they had only risen by 1.2 °F. Importantly, the product temperatures remained within acceptable limits. Because the tests were conducted in April when the outdoor air temperature was around 70 °F, the facility's load was not as high as it is during the summer. When adjusting for summer

conditions, DRRC estimated that the facility could shed up to 385 kW if a DR event were to occur.

U.S. Foodservice incurred no costs for installing the equipment and implementing the OpenADR tests, as they received a one-time installation incentive payment of \$71,000 based on the estimated load shed. Future participation in OpenADR events could enable them to receive additional incentives.

**Figure 9: Energy performance of U.S. Foodservice on a DR event day compared to DBP baseline**



### 2.2.2. 2009 CPP Analysis

As part of the continuing effort to create an improved understanding of the potentials, challenges and current state of this sector, electricity usage data from nine PG&E industrial refrigerated warehouse customers were analyzed for load sheds and load shifts from baseline during the 2009 CPP season (1-May-2009 to 31-Oct-2009). Sites included facilities following manual demand response as well as automated demand response strategies. The results confirmed the DR abilities inherent to industrial refrigerated warehouses, but showed a significant degree of variation across the different facilities analyzed (Goli *et al.* 2010).

The following representative summary observations and inferences were made from sites with average total facility-wide baseline electricity consumptions ranging from 150 kW to 1.3 MW:

1. Good sheds obtained on most of the event days at 3 facilities implied equipment capability, operational flexibility, and commitment of plant management. In fact, one of the facilities achieved a peak 90% shed via manual DR, as opposed the more typical shed of 20-40%, but it was noted that this was primarily a food processing facility rather than refrigeration or freezer, and the shed was achieved by simply shutting down production for that period.
2. Good sheds on 2-3 of the 12 event days at 4 facilities implies inherent capability, but lack of financial incentives and/or management buy-in.
3. The remaining sites showed mixed results and in the context of limited information about the equipment and operations, no additional inferences were drawn.
4. At most of the facilities the DR was, as expected, seen to be a load shift as opposed to load shed. However, over the entire 24-hour period, most sites had energy usage lower than or equal to their CPP baselines. This implies that DR in refrigerated warehouses is not at the cost of energy efficiency.

A summary of the observations on which the above inferences are based is presented in Table 1.

**Table 1: Summary of load-sheds by 9 industrial refrigerated warehouse customers of PG&E during 2009 Critical Peak Pricing (CPP) season (1-May-2009 to 31-Oct-2009)**

Facility identifier	3/10 baseline; 12P-6P (average of all CPP days)	Indication of participation
Site 1	864 kW	Sheds ranging from 10-50% on 8 of 12 CPP event days
Site 2	550 kW	90% sheds every event day from 12:00-15:00; Low baseline from 15:00-18:00
Site 3	500 kW	20-30% sheds during 11 of 12 event days (except for second consecutive CPP day)
Site 4	1.3 MW	70% sheds on the first 2 of 12 CPP days of the season; No shed on other days
Site 5	200 kW	40% shed on one day only

Site 6	625 kW	Sheds ranging from 35-55% only on last 3 events (in August)
Site 7	300 kW	Large sheds on 3 of 12 events ~ 40-70% of baseline
Site 8	153 kW	Minor sheds on most days ~15-20% of baseline.
Site 9	490 kW	Did not participate in 2009

Further analysis is limited to some due to:

1. Limited granularity of end-use information (i.e. No submetering data),
2. Limited operational information in the context of which to view the observed data, and
3. Limited information on the facility, including equipment, control systems, and foods stored.

### 2.2.3. Conclusions and Future Directions

Refrigerated warehouses have been found to be excellent candidates for demand response. Incentives can reduce the cost of obtaining control systems that are compatible with DR, in some cases even making them free. The best targets for demand reduction are the cold storage loads, lighting, and battery chargers. Refrigerated warehouse contents must be kept within a certain temperature range, but these temperature ranges can be maintained through short-term reductions in cold storage loads. DR activities have also been seen to not increase overall energy usage, showing that demand response does not have to come at the expense of energy efficiency.

An effort is also being undertaken to create a DR Strategy Guide for refrigerated warehouses. The objective of this effort is to create a roadmap, or step-by-step assessment procedure, to assist facility managers in determining how to, and whether to, go about implementing energy efficiency, manual demand response, and automated demand response opportunities. Insights gained will be used to update the previous LBNL Refrigerated Warehouse Report (Lekov *et al.* 2009).

The report is expected to address the following issues:

1. Categorization and analysis of the different types of refrigerated warehouses – Whether a particular type/size of refrigerated warehouse is more ideally suited for realizing these opportunities.

2. Energy efficiency, load shed and load shift strategies that can be employed in a refrigerated warehouse.
3. Specific areas within a refrigerated warehouse which are most suited for targeting of these opportunities.
4. Determination of the minimum state of controls and automation systems that is considered to be a prerequisite for achieving these opportunities.
5. Analysis/matrix of the current state of control systems across the landscape of California industrial refrigerated warehouses.

It may further include:

6. A quantification of financial benefits accruing to the facility from participation in these opportunities, based on a few typical time-of-use programs (e.g. PG&E's Peak Day Pricing and/or Base Interruptible Program). This will help the facility manager gauge the payback period of any upgrades required to participate in DR.
7. Recommendations concerning how policies could be framed and grants/loans structured so as to incentivize facility managers and utilities to capitalize on these opportunities.

To ensure that the final document is practical and relates well to facility managers, DRRC extended invitations to Technical Advisory Group (TAG) members to collaborate on this project in the capacity of subject matter experts and sub-contractors. Based on the response to this invitation, the DRRC determined that working with Vacom Technologies, a southern California based controls vendor, would provide access to detailed data on refrigerated warehouses not readily available from other sources and would be beneficial for our ongoing research in this area. A contract was subsequently developed that will result in input for the development of the planned DR Strategy Guide for Refrigerated Warehouses.

### **2.3. Data Centers**

In 2008, LBNL's DR and OpenADR research team selected data center facilities as a focus because of their high and increasing energy use:

- Data center energy use is expanding rapidly in California and nationally. In PG&E territory alone, data centers are estimated to consume 500 MW of peak electricity annually (EPA 2007).
- According to a 2007 U.S. EPA report, national energy consumption by servers and data centers doubled from 2000 to 2006 and, if current trends continue, will nearly double again from the 2006 level of 61 billion kWh to more than 100

billion kWh in 2011, with an estimated annual electricity cost of \$7.4 billion. An estimated 20% of this energy use is in the Pacific region alone (EPA 2007).

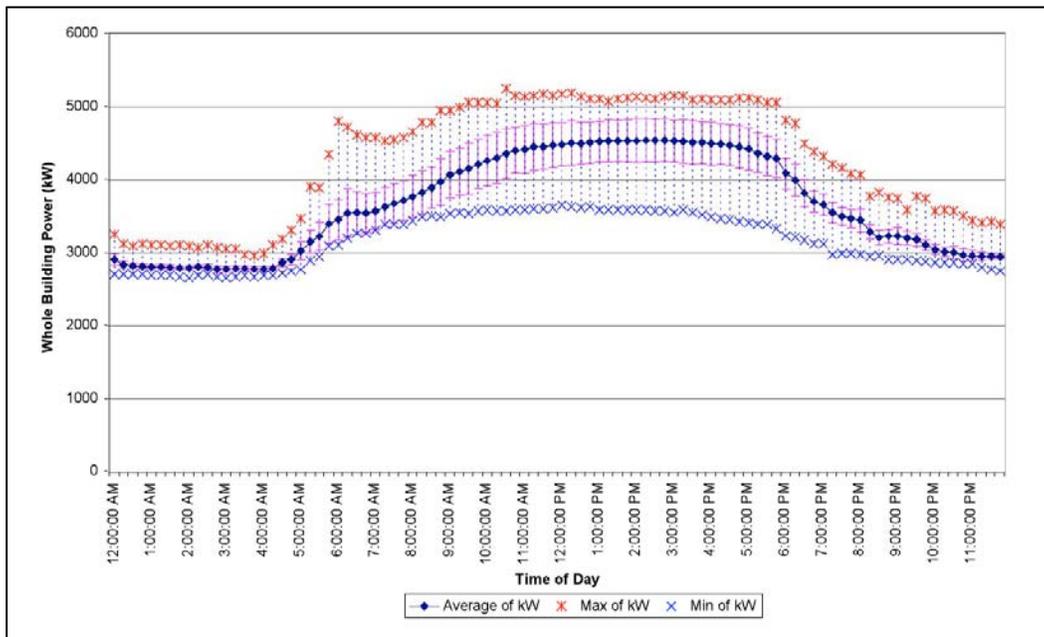
- The EPA identifies the San Francisco Bay and Los Angeles areas in California, which have the largest concentration of existing data centers in the United States as “areas of concern” and “critical” for electricity transmission congestion.
- In Silicon Valley (southern S.F. Bay region), the impact of increasing data center energy use is anticipated to be particularly significant because of the high concentration of data centers in that region.

Work done this period generated a research report entitled “Demand Response and Open Automated Demand Response Opportunities for Data Centers” (Ghatikar *et al.*, 2010). Salient aspects of the research are summarized below.

Data centers have strong DR potential. Temperature and humidity setpoints for data center zones are often maintained more strictly than ASHRAE recommendations, resulting in higher energy consumption. Significant energy savings are possible if temperature and humidity restrictions are marginally relaxed for DR periods. For mixed use data centers (facilities which also contain office space) DR sheds can be accomplished by increasing office space temperature setpoints and reducing lighting loads. Load sheds can also be accomplished by shutting down redundant cooling equipment. A modest peak reduction of 5 to 10 percent of lighting and HVAC electricity consumption within both data center and office areas in mixed-use data centers could result in significant total peak load reductions. In the PG&E territory alone, this reduction could be equivalent to 25 to 50 MW. Figure 10 shows a typical demand pattern for a mixed-use data center. Due to the office space, the typical daily load is similar to that of a commercial building, but with a high base load 24/7. Data centers without office space usually exhibit very flat load patterns.

The largest potential load reductions in data centers themselves involve reductions in information technology (IT) equipment loads. Server processor utilization rates are often low and energy savings are possible by using virtualization to consolidate processing and shut down unneeded servers. Power supplies are least efficient at low utilization rates. Consolidation of processing can lead to increased energy efficiency. For processing tasks that are not mission critical, load shifting can be achieved by queuing processing until after peak hours. As cooling loads are often roughly equal to IT equipment loads, every watt saved by IT equipment translates to a cooling load watt saved. Certain advanced IT equipment load reduction strategies may be possible, such as temporarily migrating loads to locations within different electrical zones, but require further research.

**Figure 10: Load pattern for a mixed-use data center facility summer 2007**



Obstacles to DR implementation in data centers include the perceived risk to equipment with increased temperature and humidity setpoints, the lack of control over some servers in certain data center configurations (such as co-location), and the current lack of information on DR activities at data centers.

The results from this study indicate the need for field tests and comprehensive analysis of DR strategies for data centers. Key elements for the next phases of research in this area are:

- Field tests, data collection, and demonstration of DR and Auto-DR strategies for data centers to determine effective strategies, and evaluation of the whole-facility load reduction potential against existing baselines.
- Evaluation of data center data management approaches, monitoring systems, connectivity requirements, and control system designs that will lead to a better understanding of the sequence of operations needed for in-depth DR strategy analysis.
- Education and outreach aimed at high-tech companies and organizations, such as the Green Grid, to advance DR as a higher technical priority.
- Identification of emerging data center technologies, vendors, and control strategies to reduce peak electrical load(s) for both data center IT equipment and HVAC loads.
- Identification of DR-ready, scalable, vendor-neutral, energy-efficiency technologies that can integrate within the existing utility Auto-DR infrastructure.

- Evaluation of measurement metrics for combined IT and site infrastructure performance during DR events to permit calculation of load shed, settlement, and economic value.
- With increasing grid integration with intermittent energy resources (such as wind/solar), determine the flexibility of data center loads to respond with different DR program dispatches.

## 2.4. Cement Manufacturing

In 2009, DRRC conducted a scoping study on the potential for energy efficiency and DR at cement plants (Olsen *et al.* 2010). As it is very energy intensive, the cement industry was one of the sectors that DRRC had identified as a good candidate for demand response and industrial energy efficiency measures. In the United States alone over 350 trillion Btu of fuel and 10 billion kWh of electricity are consumed annually (United States Geological Survey 2008). A 2005 case study of the 31 sites comprising the California cement industry estimated potential annual energy savings of 360 million kWh of electricity and 7.8 trillion Btu of fuel, a 20% reduction compared to 2005 energy use (Coito *et al.*, 2005). Large energy savings are possible by upgrading mills, separators, and fan drives to more modern, energy efficient models.

While several of the studies to date have focused on energy efficiency, research does indicate that the application of DR strategies to the cement industry is feasible. The majority of energy consumed at cement plants is used in the kiln in the form of fuel, which must be continuously supplied to the kiln. Electrical loads tied to the kiln system cannot be stopped or shifted without loss of product or damage to the kiln. Potential for demand response exists in quarrying operations, raw mix grinding, fuel grinding, and clinker grinding. These processes, unlike kiln operation, are non-continuous. Their interruptibility is dependent on the amount of storage present at various points in the cement process, the capacities of the mills compared to the kiln, and the types of mills used in grinding. In order for raw mills to be shut down, there must be enough raw mix in the silo to supply the kiln until the mill comes back online. The cement mill can also be shut down as long as stores of finished cement outlast cement shipments until the cement mill is reactivated. A small amount of product cement does get discarded in the process of shutting down the cement mill, but clinker coming from the cooler is simply stockpiled for later use.

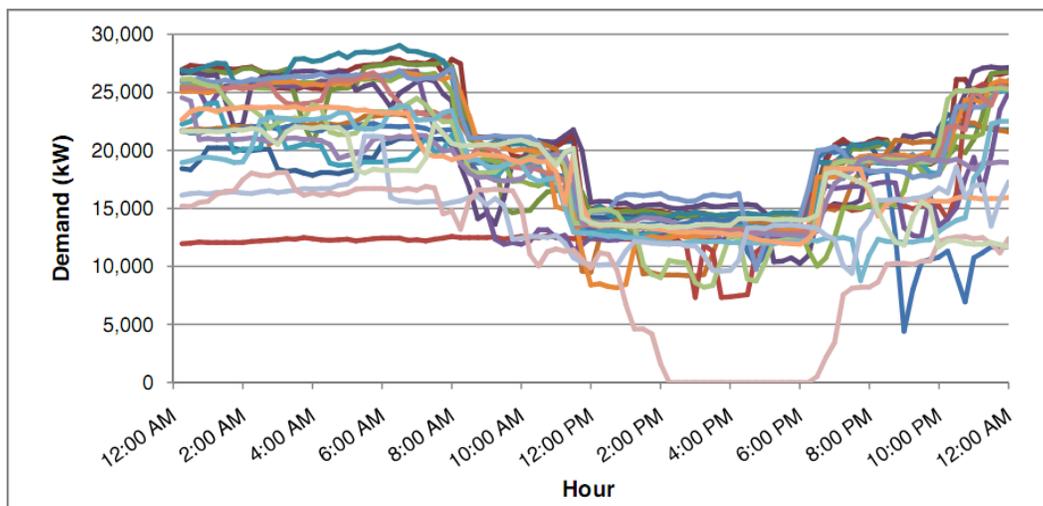
There is also the possibility of scheduling certain equipment to run during off-peak hours, in what has been referred to as “permanent load shift”. The possibility of implementing Auto-DR is dependent on the level of controls and the comfort level of plant management. Also, since continuous processes inherently run most efficiently

with steady operation, for load shedding to be feasible the financial incentives from the utility must outweigh the cost of stopping and starting these mills, which can include extra electrical energy, operator time, and loss of product.

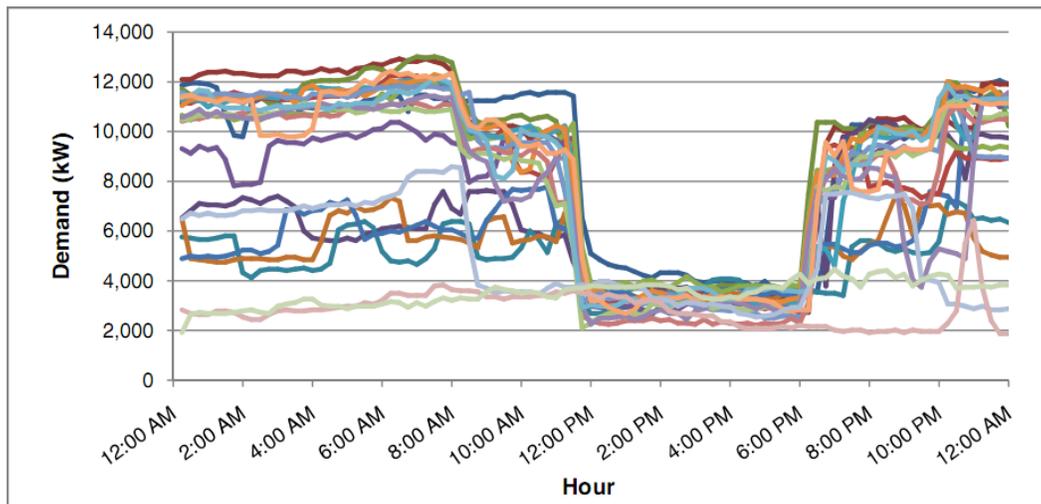
In 1997, Bosowa began construction on a new cement plant in South Sulawesi, Indonesia. Their cement grinding circuit consisted of a hydraulic roll press, a high efficiency separator, and one large ball mill powered by a 5.5 MW gearless mill drive. Due to the high capacity of the grinding circuit, plant operators were able to shut down the cement mill for several hours per day. By scheduling all of their finish grinding to occur during off-peak hours with lower electrical rates, the plant estimated savings of over \$1 million per year in energy costs.

Energy use data was collected and analyzed from the Lehigh Permanente cement plant in Cupertino, California. During summer months, the plant's energy use is scheduled around an electricity tariff that incorporates weekday off-peak, partial-peak, and on-peak hours. Weekdays in August 2009, average partial-peak demand was 5 MW less than during off-peak hours, and average on-peak demand was 9 MW less than during off-peak hours, as seen in Figure 11. Weekdays in September 2009, during a kiln shutdown, average on-peak demand was 6 MW less than during off-peak hours, as seen in Figure 12. These load shifts were accomplished by scheduling the raw mills and quarry operations based on time-of-use energy costs. Stores of crushed limestone and raw mix at the plant are large enough to last for days if necessary, so responding to a demand response event by shutting down raw mills and quarrying should have no impact on plant operation.

**Figure 11: Electrical power used by Hanson Permanente weekdays during August 2009**



**Figure 12: Electrical power used by Hanson Permanente weekdays during September 2009**



## 2.5. Industrial Controls Survey

Beginning in November of 2009, a web based survey was conducted on DR participation and controls capability in California industrial facilities. The research objectives were to investigate the status of industrial controls in California and the link between control capabilities and DR in order to be able to target industrial sectors that have the greatest technical potential for Auto-DR. Outreach by the DRRC was conducted via key trade associations, conference presentations, interactions with control system vendors, and direct calls to industrial facilities. The goal was to gather at least 50 survey responses across a broad cross section of industrial sectors.

By February of 2011, 46 valid survey responses had been collected. Facilities were categorized according to 4-digit NAICS code. Preliminary findings obtained from these responses were presented to a group of industrial control experts, whose feedback was used to refine the preliminary conclusions as well as to suggest industrial sectors with DR potential which may have not been captured in survey responses. Key findings are as follows:

The link between control capabilities and DR is real—though only about a third of survey respondents were DR participants, a majority of the facilities with fully-automated process control were DR participants, and vice versa.

- There are a set of characteristics that support DR participation, which include advanced control systems, predictable loads, and a history of energy efficiency measures.

- Within broad industrial sectors there are many smaller sub-sectors whose operational nuances and thus potential for DR cannot be captured at the broad sectoral level.

Potential next steps identified include: identify common shed/shift strategies proven not to impact operations, further investigate industrial sectors identified by the report as having inherent DR potential, and increase the data set of the control survey in order to gain a more comprehensive assessment of the controls of California industry. The final report on the survey was released in January 2012.

## 2.6. Ancillary Services

Ancillary services are defined by the Federal Energy Regulatory Commission (FERC) as those “necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system.” In light of the California mandate for 33% of power to be generated by renewable sources by 2020 and the fact that renewable resources are often intermittent and unpredictable, demand response in the ancillary services market is becoming increasingly important.

During this period, the DRRC began research on the challenges and opportunities of integration of renewable resources into California’s electrical grid. This generated:

- A scoping study entitled “Integrating Renewable Resources in California and the Role of Automated Demand Response” (Kiliccote *et al.* 2010) and
- A research report entitled “Automated Demand Response as a Grid Balancing Resource for the Integration of Renewables” (Watson *et al.* 2012).

Pertinent aspects of the research are summarized below.

The specific operational challenges posed by the large scale integration of variable generation resources are:

- The magnitude of hourly overall ramping requirements,
- Intra-hour variability,
- Over-generation issues (particularly wind), and
- Large, near-instantaneous production ramps (particularly solar) (Kiliccote *et al.* 2010).

The California Independent System Operator (CAISO) currently purchases four different types of ancillary services: regulation up, regulation down, non-spinning reserves, and spinning reserves. Spinning and non-spinning reserves are generation

capacity that can be brought online to a bid capacity, and regulation up and down are bids to increase or decrease generation to balance minute-to-minute imbalances. Of these, Auto-DR is currently approved for all but spinning reserves. Demand response sheds for ancillary services must occur with little or no advanced notice, ramp faster and last for shorter durations. The characteristics of the CAISO products are summarized in Table 2.

**Table 2: CAISO Programs Suitable for Auto-DR**

Auto-DR Approved for CAISO use	Existing CAISO products	Response Time	Duration
	Regulation Up	Start <1 min. Reach bid <10 min.	15 - 60 min.
	Regulation Down	Start <1 min. Reach bid <10 min.	15 - 60 min.
	Non-Spinning Reserves	< 10 minutes	30 min.
Future (?)	Spinning Reserves	~ Instant Start Full Output <10 min.	30 min.

Auto-DR enabled loads have the potential to offset the higher penetration of variable resources by shifting some load from peak to off-peak or nighttime, managing (reducing) daily peaks, and smoothing ramps associated with rapid variations in energy supplied by in renewable sources. Based on the current penetration of automated controls at commercial and industrial facilities throughout California, a large-scale deployment of Auto-DR could provide between 0.25 and 0.8 GW of DR-based ancillary services. However, this refers to technical potential only; economic, regulatory, and organizational barriers reduce the ability of loads to participate in Auto-DR. Substantially increasing the penetration of automated control systems in facilities that are currently “unreachable” by Auto-DR could approximately double the estimated shed potential to between 0.4 and 1.8 GW (Watson *et al.* 2010). The shed availability and controllability estimates for industrial loads used to generate the estimated shed potential are shown in Table 3.

**Table 3: Industrial End Uses – Shed Availability and Controllability\***

Industrial Type	Shed Availability (% of Demand)		Controllability (% of Demand able to receive and execute DR signals at targeted end use)	
	Slow DR (2 Hour shed)	Fast DR (20 minute shed)	Current %	Technical Potential %
Refrigeration – Frozen Storage Refrigerated Warehouse	25%	35%	40%	80%

Refrigeration – Cold Storage Refrigerated Warehouse	5%	35%	25%	50%
Data Centers	15%	15%	75%	100%

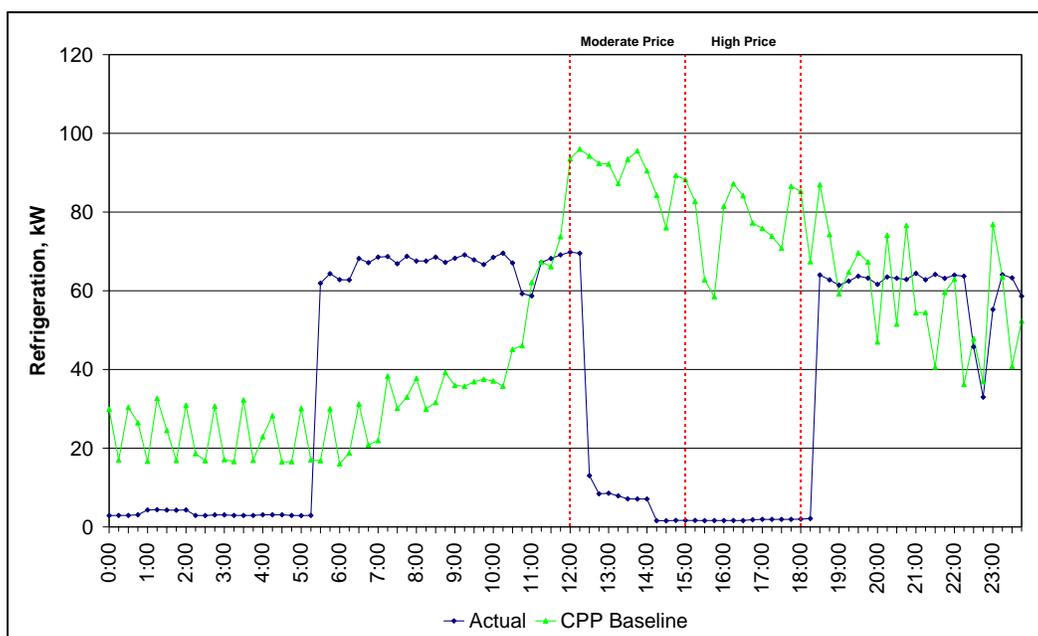
\*Estimates for Agricultural Pumping pending future research

## 2.7. Other Research

### 2.7.1. End-use submetering

During the summer of 2007, five industrial sites and one commercial site were submetered for key end-use loads. Consistent sheds and shifts were observed at four of the sites. Lighting and plug loads were shed at a chemical repackaging facility, refrigeration loads were shifted at an agricultural processing and cold storage facility (as seen in Figure 13), and operation of a pan washer was shifted at a bakery. One other site (a baking & frozen foods facility) showed consistent load sheds, but for loads that were not submetered. Only one of the sites participated in Auto-DR: the bakery which automatically shut off its pan washer and shifted pan washing to off-peak hours. Submetering was seen to provide significant advantages over whole-facility load monitoring, as increased power draw in some loads can cancel out successful DR implementations for other loads, details which would be lost looking only at whole-facility load.

**Figure 13: Power consumption of refrigeration loads at an agricultural processing and cold storage facility on a CPP event day, showing evidence of pre-cooling**



### 2.7.2. Auto-DR Assessment Site Visits by LBNL and GEP

During this period, DRRC accompanied Global Energy Partners (GEP) on a number of joint field visits to industrial sites participating in PG&E's Auto-DR programs. These included refrigerated warehouses, wastewater treatment plants, and data centers.

Two site visits are summarized here:

- Industrial Team members visited the Froszun Foods warehouse in Santa Maria in July 2010 to assess their Auto-DR control system implementation. Due to some last minute commissioning issues by the vendor, the planned Auto-DR shutdown didn't take place that day. Nevertheless, it provided an opportunity to hear the plant engineers, technicians and operators' feedback on the control system and assess firsthand the layout of a large refrigerated warehouse with nearly 4 MW of installed refrigeration capacity.
- A visit was made to HMC Foods in Kingsburg, near Fresno, in September 2010, to witness their Auto-DR test under PG&E's Demand Bidding Program (DBP). This is primarily a refrigeration facility, with minimal processing operations. Grapes, peaches, nectarines, citrus, and plums are stored in the facility at 34-36 °F. The original plant control system, as well as the additional Auto-DR capability, was installed by Cold Storage Technologies Inc. The plant has a summer day peak demand of approximately 2.4 MW (48% refrigeration, 36% fan, 4% packing, 4% lighting and 8% miscellaneous loads including battery chargers). The plant's Auto-DR control strategy is programmed to shed up to 400 kW of the refrigeration loads. On the test day, due to milder weather and lower product throughput, the plant's total load was 466 kW at 2pm, when the event was called. When the event signal was received at the facility, the Auto-DR logic controller initiated a 2 minute load reduction ramp to a total plant power set point of 302 kW. This load level was maintained till 4 pm, the end of the event period. After the event ended, the power consumption ramped up above 480 kW before gradually trending back down to below 460 kW. This "rebound" effect must be managed carefully to avoid paying increased demand charges.

The Industrial Team plans to continue industrial site evaluations to determine their suitability for Auto-DR in order to contribute to the body of research on practical vs. theoretical Auto-DR sheds and shifts.

### 2.7.3. Smart Grid and Industrial Auto-DR

Participation continued in the Industry to Grid (I2G) Domain Expert Working Group of the Smart Grid Interoperability Panel. During this period, contributions were made to the *I2G Interoperability Assessment, Roadmap and Recommendations Working Draft*,

particularly in the area of industrial management practices and control strategies. The working draft set forth key factors that characterize the relationship between industry and the utilities that would need to be addressed in order to transform this relationship. The goal would be a relationship that is one of collaboration for the purpose of improving the reliability of the grid for all customers. These factors include:

- Industrial facilities often engage in long-term operations planning and therefore may not be adequately incented to develop near real-time interoperability for Smart Grid participation.
- Many industrial facilities with a significant electric power-to-revenue ratio utilize energy management technology to minimize the impact of electricity on operating costs.
- Many large industrial facilities have on-site generation capability and can net export power to the grid but are often limited by local regulations.

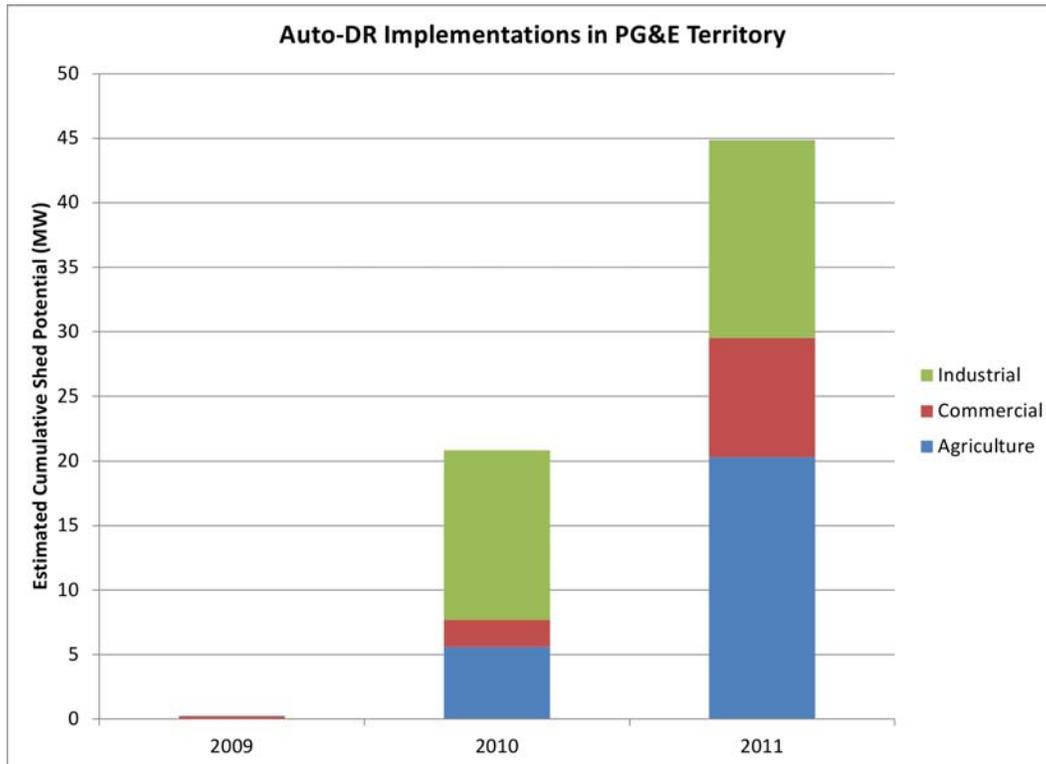
The potential for industry to participate as a decentralized supplier of electricity through onsite generation was emphasized. Realizing this potential would require increased involvement by industrial customers in the definition of interoperability requirements, including cybersecurity concerns.

More recently, I2G has focused on the development of an Energy Services Interface white paper, for the purpose of developing a better understanding of the interfaces between the loads, storage and generation in facilities and the grid. Improved understanding would facilitate various energy transactions and meet the needs of today's grid interaction models, such as demand response and distributed energy resources, as well as those of tomorrow's market interactions.

#### 2.7.4. Auto-DR Installations

A brief analysis was conducted on the proliferation of Auto-DR in commercial, agricultural and industrial facilities. Data on customer enrollment of Auto-DR enabled loads was obtained from PG&E. Corresponding data from the other California is expected in the future. Based on this preliminary information, the Auto-DR enabled shed potential in California seems to be increasing at an accelerating rate. Four service accounts were Auto-DR participants in 2009, and by August 2011 nearly 200 service accounts were participants. The estimated shed potential also grew from less than a megawatt in 2009 to a projection of nearly 45 megawatts by the end of 2011, as seen in Figure 14. The largest gain in the past year has been in the agricultural sector.

**Figure 14: Cumulative Auto-DR enabled shed potential of the industrial, commercial, and agricultural sectors in PG&E territory**



### 3.0 Areas for Future Research

The DRRC's research plans for the upcoming period target areas of potential based on current research, in line with the CEC's priorities. This includes continuing research into the previously identified sectors of refrigerated warehouses, wastewater treatment, and data centers, as well as newly identified areas such as agricultural irrigation and an additional sector of promise emerging from the Controls Survey.

Refrigerated warehouses will continue to be an area of study due to their unique position of being able to use the thermal mass of frozen or refrigerated food contained therein as a storage medium for load shift and grid response. To improve the outreach value of our ongoing research, a "strategy guide" will be developed that facility managers can use as a resource in their DR implementation planning. Additional investigations will include the effect of parameters (e.g. energy use, building characteristics, load profiles) and sufficiency of current data to write a memo addressing whether it is practical to develop decision making tools, such as a DR Quick Assessment Tool (similar in scope to the DR-QAT developed earlier for buildings). Towards this end, collaborations will also be explored with stakeholders who might have access to large amounts of operating data and/or who have already been involved in modeling or tool-development. Relevant information will then go into refining the Phase I research report (Lekov 2009) previously developed.

Wastewater treatment plants may have the flexibility to use their intermediate wastewater treatment stages as a non-thermal process/material storage medium. As part of our continuing research we will review literature and gather expert feedback to evaluate the conditions under which this characteristic can be harnessed for load shifting/shedding and grid response. An issues paper will be prepared which may serve as the basis for a future DR Strategy Guide scoping draft, by drawing on literature survey, sub-metering analysis, survey results and expert input.

The agricultural irrigation sector is another promising area for energy management that the CEC's Public Interest Energy Research program has expressed particular interest in. California agricultural irrigation consumes more than 10 billion kWh of electricity annually, almost entirely between the months of May and October, which is also the period of greatest stress on the electricity grid. The soil beneath irrigated crops acts as a large water storage medium, allowing some flexibility in pump scheduling. A methodology for estimating the DR potential of a farm was developed as part of a utilities funded project, and foreseen future work may include developing a unified approach to agricultural water energy management.

## 4.0 Conclusion

The Industrial-Agricultural-Water (IAW) sector has the potential to generate a wide range of energy related benefits for the State of California. These include increased reliability of the electrical grid, lower costs of generating electricity, providing electricity “storage capacity” for the assimilation of a greater amount of intermittent renewable resource generation capacity, and the creation of associated specialized jobs. Further, IAW accounted for 30% out of the 60 GW of peak electric load in California in 2010, and thus has the potential to be a key contributor to the Demand Response (DR) and Energy Efficiency (EE) space.

DRRC’s research to date has focused on the sectors of refrigerated warehouses, wastewater treatment, data centers and agricultural irrigation, all found to be areas of potential. In addition, the Industrial Controls Survey identified characteristics that appear to be conducive to DR ability in a sector. Adequately sophisticated control technologies installed for EE and load management purposes can often be adapted for DR and Automated Demand Response (Auto-DR) at reduced incremental cost. Auto-DR may be utilizable to more consistently achieve peak period load reduction without impacting operations. Based on this a more granular approach incorporating expert opinion was found to be better suited to identifying additional sub-sectors of promise for future studies.

Potential barriers and outstanding issues to be addressed through future research include the fact that industrial facilities are not primarily concerned with DR, the focus being on their own production. Therefore, unless the technology platform is showcased, operational flexibilities demonstrated and financial incentives evident, many facilities are not willing to consider the potential benefits of DR. Future research will attempt to address this issue.

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## 6.0 Glossary

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
Auto-DR	Automated Demand Response
Btu	British Thermal Unit
CAISO	California Independent System Operator
CEC	California Energy Commission
CPUC	California Public Utilities Commission
CPP	Critical Peak Pricing
DBP	Demand Bidding Program
DR	Demand Response
DRRC	Demand Response Research Center
EE	Energy Efficiency
EMCS	Energy Management Control System
EPA	Environmental Protection Agency
FERC	Federal Energy Regulatory Commission
GEP	Global Energy Partners
GW	Gigawatt
HVAC	Heating, Ventilation and Air Conditioning
IAW	Industrial Agricultural and Water
IT	Information Technology
kWh	Kilowatt hour
LBNL	Lawrence Berkeley National Laboratory
MW	Megawatt
NAICS	North American Industrial Classification System
OpenADR	Open Automated Demand Response
PG&E	Pacific Gas and Electric Company
PIER	Public Interest Energy Research
PLC	Programmable Logic Controller
SCADA	Supervisory Control and Data Acquisition
TAG	Technical Advisory Group

# Appendix A. Prior Research

The key findings of the previous report (LBNL-1335E, McKane *et al.*, 2008) were:

1. There appears to be great potential for Auto-DR in industrial facilities. This finding needs to be qualified with further research to understand 1) organizational decision-making processes as they impact DR participation, 2) the role of existing and emerging industrial controls in facilitating participation in Auto-DR, and 3) end-use process controls to support reduced service and process control levels during DR events.
2. Auto-DR is compatible with energy efficiency and load management in industrial facilities. Plants who express interest in Auto-DR are typically already engaged in both energy efficiency and demand management improvements. Auto-DR is another cost-reduction tool, not a replacement for efficiency and demand management.
3. Many industries have limited controls, especially for supporting or non-core systems that may be suited for Auto-DR. There is an emerging market for demand management and system-level network controls that could allow Auto-DR to be integrated.
4. Nine 4-digit NAICS categories were identified as in the top-25 for both large users of manufacturing electricity and DR potential by average kW from the utility integrated audits. The nine sectors identified were compared against recommendations in other related reports, and an initial “short list” of five industrial sectors recommended for further study based on knowledge of these sectors. These sectors are listed in Table A-1.

**Table A-1: Industrial sectors of interest**

NAICS top-25 electrical energy users	Recommended short list
<ul style="list-style-type: none"> <li>• Converted Paper Product manufacturing</li> <li>• Fruit and Vegetable Preserving and Specialty Food Manufacturing</li> <li>• Basic chemical manufacturing, especially industrial gases</li> <li>• Dairy Product manufacturing</li> <li>• Aerospace Product and Parts Manufacturing</li> <li>• Other Fabricated Metal Product Manufacturing</li> <li>• Animal Slaughtering and Processing</li> <li>• Bakeries and Tortilla Manufacturing</li> <li>• Beverage Manufacturing</li> </ul>	<ul style="list-style-type: none"> <li>• Cold storage</li> <li>• Data centers and test labs for high tech industries</li> <li>• Water/wastewater</li> <li>• Aerospace products</li> <li>• Beverages, including breweries and wineries</li> </ul>

5. Industrial facilities are not concerned with DR, since their focus is on core production. However, some industrial facilities will shift or shed process load based on financial incentives, not just to protect reliability.
  - a. In certain niche markets, such as industrial gases, electricity is a large proportion of operating costs. As a result, demand management is an integral part of the operating culture with sophisticated controls. For these markets, Auto-DR offers a cost-management opportunity that can be readily integrated into the production schedule.
  - b. The current portfolio of DR programs is confusing, but the availability of financial incentives and technical assistance can make participation attractive.
6. There is a wide range of potential shift and shed strategies requiring further study, those most frequently identified in the utility integrated audits are:
  - a. For production shifts - conveyors, all systems, pump systems, and electrical
  - b. For production sheds - all systems (stop production), finishing, process cooling and pump systems
  - c. For supporting system load shifts - space conditioning, motors, process cooling, and storage
  - d. For supporting system load sheds - aerators, multiple systems, electrical, and compressed air.

Based on the insights gathered from above prior period research, for the current period, the DRRC had planned to continue working in sectors showing good DR potential with Technical Advisory Groups (TAG) comprised of representatives from industry and the suppliers and consultants that work with them. Figure 1 in the body of the report shows the organizational framework of research that had been foreseen for the current period, directed toward key research questions outlined above to assist the California Energy Commission (CEC), the California Public Utilities Commission (CPUC), and the investor-owned utilities in more effectively targeting their Auto-DR efforts.